Influence of oscillating dietary crude protein concentration on performance, acid-base balance, and nitrogen excretion of steers[1,2,3]

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ABSTRACT: Decreasing dietary N inputs into beef cattle feeding operations could potentially decrease environmental concerns relating to air and water quality. Previous studies with sheep suggest that oscillating dietary CP concentrations may improve N use efficiency and thereby decrease dietary N requirements. Therefore, two studies were conducted to determine the effects of oscillating dietary CP concentrations on performance, acid-base balance, and manure characteristics of steers fed high-concentrate diets. Steers were fed to a constant backfat thickness in both studies. In the first trial, 92 steers (mean BW = 408 ± 2.8 kg; four pens/ treatment) were fed the following diets: 1) constant 12% CP, 2) constant 14% CP, and 3) 10 and 14% CP oscillated at 2-d intervals. Steer performance and carcass characteristics were measured. In the second trial, 27 steers were individually fed the same three experimental dietary regimens (nine steers/treatment). Animal performance, arterial acid-base balance, plasma metabolites, and fecal characteristics were measured. In both trials, steers fed the 14% CP diet tended ($P < 0.10$) to have greater ADG and gain:feed than steers fed the 12% CP diet. Steers fed the oscillating CP regimen had intermediate performance. In Trial 1, steers fed the 14% CP diet tended ($P = 0.09$) to have smaller longissimus area and higher quality grades than steers fed the oscillating CP regimen. Protein retentions (g/d) calculated from NRC (2000) equations were greater ($P = 0.04$) for steers fed the 14% CP diet than steers fed the 12% CP diet. Steers fed the oscillating CP regimen tended ($P = 0.08$) to have greater calculated protein retention (g/d) than steers fed the 12% CP diet. Steers fed the 14% CP diet had greater ($P < 0.05$) calculated urinary N excretion than steers fed the 12% CP or oscillating CP regimens. Venous plasma concentrations of urea N were greater ($P < 0.001$) in steers fed the 14% CP diet than in steers fed the 12% CP diet; steers fed the oscillating CP regimen were intermediate but fluctuated over days. Based on arterial blood gas concentrations, acid-base balance was not significantly affected by dietary CP regimen. Results of these trials suggest that the CP requirement of steers in these studies was greater than 12% of the diet DM, and/or that the degradable CP requirement was greater than 6.3% of diet DM. However, the effects of oscillating dietary CP were minimal.

Key Words: Acid-Base Balance, Beef Cattle, Nitrogen, Protein

Introduction

There are increased concerns about the effects of confined livestock feeding operations on air and water quality. Feeding cattle in confinement can lead to the concentration of nutrients, such as N and P. Ideally, most of these nutrients will be captured in manure that is subsequently used as a fertilizer for crops. However, significant quantities of N can be lost to the atmosphere (Bierman et al., 1999) as ammonia or dinitrogen gas (Hutchinson et al., 1982; Harper et al., 2000). Decreasing the quantity of N fed could potentially decrease these atmospheric losses but could also adversely affect animal performance.

Results of a lamb N balance study (Cole, 1999) suggested that oscillating the dietary CP concentration of high-concentrate diets between relatively high and relatively low (moderately deficient) concentrations may increase the efficiency of N utilization and thus decrease the quantity of N required for optimum perfor-

Table 1. Composition of diets, % DM basis[a]

Item	10 %	12%	14%
Steam flaked corn	80.0	80.0	80.0
Sudan hay	5.0	5.0	5.0
Cottonseed hulls	5.0	5.0	5.0
Supplement[b]	10.0	10.0	10.0
Chemical component[c]			
CP, %	10.0	12.1	14.1
DIP, %	4.4	6.3	8.1
Ca, %	0.55	0.55	0.55
Mg, %	0.18	0.18	0.19
P, %	0.34	0.35	0.36
NEg, mcal/kg	1.39	1.38	1.37

[a]Diets containing 12% CP were a 50:50 blend of 10% CP and 14% CP diets.

[b]See Table 2. Each supplement was specifically formulated for each diet and contained the following: ammonium sulfate, salt, cobalt chloride-hexahydrate, copper sulfate-pentahydrate, potassium iodide, iron sulfate, manganese sulfate, potassium chloride, sodium selenite, zinc sulfate-heptahydrate, vitamin E (227,000 IU/kg), vitamin A (291 million IU/kg), Tylan (88 g tylosin/kg: Elanco Animal Health), and Rumensin (176 mg monensin/kg: Elanco Animal Health).

[c]Crude protein and phosphorus values were determined analytically, and other values were calculated from NRC (2000). DIP = degradable intake protein.

Table 2. Composition of supplements, % DM basis[a]

Item	10%	12%	14%
Ground sorghum	76.60	52.35	28.10
Cottonseed meal	0	20.00	40.00
Urea	0	5.00	10.00
Ammonium sulfate	2.00	2.00	2.00
Limestone	10.00	10.00	10.00
Magnesium oxide	0.50	0.25	0
Potassium chloride	5.00	4.50	4.00
Salt	3.00	3.00	3.00
Vitamin E (104,000 IU/kg)	0.06	0.06	0.06
Vitamin A (132 million IU /kg)	0.01	0.01	0.01
Tylosin (18.2 g/kg)[b]	0.13	0.13	0.13
Monensin (36 g/kg)[b]	0.20	0.20	0.20
Trace mineral package[c]	2.50	2.50	2.50

[a]12% supplement was a 50:50 blend of the 10% and 14% supplements.

[b]Tylan and Rumensin, respectively; products of Elanco Animal Health, Greenfield, IN.

[c]Contained the following: Co as cobalt carbonate 0.34%; Cu as copper sulfate-pentahydrate 3.0%; I as potassium iodide 0.07%; Fe, as ferrous sulfate 1.7%; Mn as manganese sulfate 17%; Se as sodium selenite 0.06%; and Zn as zinc sulfate-heptahydrate 27%.

mance. However, ammonia may serve as a major urinary/systemic buffer during metabolic acidosis (Heitmann and Bergman, 1978; Trenkle, 1979). Thus, under typical feeding conditions, decreasing dietary CP concentrations could potentially have adverse effects on feed intake and health of feeder cattle (Galyean, 1996).

These studies were conducted in order to gain more information on the effects of an oscillating dietary CP feeding regimen on the performance, N excretion, plasma metabolite, and acid-base balance of steers fed high-concentrate diets.

Materials and Methods

The experimental protocols were approved by the Animal Care and Use Committee of the Cooperative Research, Education, and Extension Triangle. Animals were handled in accordance with published guidelines (FASS, 1999).

Performance: Trial 1

Ninety-two crossbred steers (average BW = 408 ± 2.7 kg) that had been maintained on native grass pastures for the previous 5 mo were used. On August 20, 2000, steers were individually weighed and randomly assigned to 1 of 12 pens with a soil surface and fence line feed bunks. Steers were initially fed a common 60% concentrate diet for 2 wk and a common 75% concentrate diet for 1 wk before they were fed the 90% concentrate experimental finishing diets (Tables 1 and 2) for the remainder of the trial. Four pens of steers were continuously fed a finishing diet with 14% CP containing 1% urea, four pens were continuously fed a 12% CP diet, and the remaining four pens were fed

oscillating concentrations of CP (10 or 14% CP) at 2-d intervals. All diets were formulated to meet vitamin and mineral requirements (NRC, 2000) and contained 10% roughage, Rumensin, and Tylan (Elanco Animal Health, Greenfield, IN). Based on NRC (2000), the 10% CP diet was calculated to be moderately deficient in CP and degradable intake protein (**DIP**), the 12% CP diet was calculated to be borderline deficient to adequate in CP and DIP, and the 14% CP diet was calculated to be adequate to slightly excessive in CP and DIP. Cattle were fed once daily at 0800 to provide approximately 0.5 to 2.5 kg of daily orts per pen. Feed samples were obtained each week, frozen, and composited within each month of the trial. If present, orts from each pen were weighed and sampled each week.

Steers were initially implanted with Synovex-S (20 mg of estradiol benzoate and 200 mg of progesterone; Fort Dodge Animal Health, Overland Park, KS) and reimplanted at 56 d on feed with Revalor-S (24 mg of estradiol 17β and 120 mg of trenbolone acetate; Intervet, Millsboro, DE). Steers were individually weighed unshrunk at 28-d intervals until d 84. On d 56 of the trial, ultrasound measurements were taken to determine fat thickness and marbling scores using an Aloka 500 Ultrasound equipped with a 3.5-MHz, 17.2-cm linear array transducer (Corometrics Medical Systems, Inc., Wallingford, CT). Individual steers were selected from pens for slaughter when their projected backfat thickness, based on ultrasound measurements, was 1 cm (Brethour, 2000a,b). Steers were harvested in a total of four groups at a commercial packing plant near Amarillo, TX. Carcass data were obtained by the Carcass Data Grading Service at West Texas A&M University after a 48-h chilling period. Final individual BW were determined by dividing individual hot carcass weights by the average dressing percentage for cattle in that harvest group.

Data were statistically analyzed by ANOVA as a randomized complete block design with pens as experimental units using the PROC GLM procedure of SAS (SAS Inst. Inc., Cary, NC). Pens were blocked by location in the experimental feedlot. The block × treatment interaction mean square was used as the error term. Diet effects were tested by the multiple t-test of SAS. The quality grade distribution and proportion of steers with abscessed livers were tested by chi-squared analysis.

Individually Fed Steer Study: Trial 2

Twenty-seven steers (average BW = 405 ± 4.5 kg) from native pastures were used in the study. Steers were trained to eat from individual feeders (American Calan, Northwood, NH) then were weighed, implanted with Synovex-S, and randomly assigned to three pens with nine steers/per pen. Within each pen, three steers were randomly assigned to each of the three dietary regimens used in Trial 1. Steers were individually fed once daily at 0800; feed additions were recorded daily and orts were weighed and sampled at 7-d intervals. Steers were individually weighed unshrunk on d 28 and 56.

Before the morning feeding on d 14 through 17 of the trial, heparinized arterial blood samples were obtained from the ear (PICO 70 samplers, Radiometer America Inc., Westlake, OH), and blood samples for plasma were obtained from the jugular vein with plastic syringes containing K-EDTA as an anticoagulant (Sarstedt, Inc., Newton, NC). Additional venous blood samples were obtained on d 42 through 45. The 4-d sampling was used in order to determine the effect of dietary changes on acid-base status and plasma metabolite concentrations. Plasma was harvested from venous blood by centrifugation at $3,000 \times g$ at $10°C$ for 30 min and stored frozen until analyzed. Arterial samples were analyzed immediately after collection for pH, pCO_2, and pO_2 using ion selective electrode methodology on an IRMA Series 2000 Blood Analysis System (Diametrics Medical, St. Paul, MN). The analyzer calculated blood bicarbonate, total carbon dioxide, blood base excess, extracellular fluid base excess, and O_2 saturation based on the Siggaard-Anderson formulas (Houpt, 1982). Plasma ammonia (Sigma Chemical, St. Louis, MO; Kit # 171), urea-N (Sigma Kit # 535), chloride (Sigma Kit # 461), glucose (Sigma Kit # 510), and lactate (Sigma Kit # 735) concentrations were determined colorimetrically using commercial kits.

Each morning of d 14 through 17, fecal samples were obtained from each steer. A portion of the sample was mixed with deionized water (5 g:5 mL) and allowed to stand for 2 min; the pH was determined using a combination electrode. The remainder of the sample was stored frozen until analyzed.

Nitrogen and P concentrations of diets, orts, and feces were determined colorimetrically using a Technicon Autoanalyzer after wet digestion (Technicon, 1977). Dry matter of feed, orts, and feces was determined by

drying to a constant weight at $60°C$ (AOAC, 1990). Feces and feed samples were analyzed for the internal marker acid-insoluble ash by the method of VanKeulen and Young (1977) to calculate apparent digestibility and fecal N excretion. Energy and protein retention of individual steers were calculated using NRC (2000) equations. Urinary N excretion was estimated as the difference between N intake and the sum of fecal N + retained N.

Performance data were statistically analyzed by ANOVA as a completely randomized design with steers as experimental units using the PROC GLM procedure of SAS. Diet effects on performance were determined using the Waller Duncan k-ratio multiple t-test of SAS. Treatment effects were tested using steer(treatment) as the error term. Arterial whole blood, venous plasma, and feces data were analyzed by PROC MIXED as a repeated measures experiment with main effects in a completely randomized design.

Results and Discussion

Performance: Trial 1

Steer ADG and gain:feed during the first 56 d were not significantly affected by dietary regimen (Table 3) although steers fed the 14% CP diet had greater ($P = 0.04$) DMI than steers fed the other dietary treatments. However, at the conclusion of the feeding study, steers fed the 14% CP diet had greater ($P = 0.04$) ADG and tended ($P = 0.09$) to have greater gain:feed than steers fed the 12% CP diet. Steers fed the oscillating CP regimen had intermediate performance. It is probable that at least a portion of these differences were due to differences in DIP content of the diets. The NRC (2000) suggests that the minimum requirement for DIP is 6.8% of dietary DM, whereas the DIP of the 12% CP diet was 6.3% of DM.

The effects of oscillating dietary CP on performance in the present study tend to agree with results of Collins and Pritchard (1992) and Ciminski et al. (2000), who also noted numerically greater ADG in steers fed oscillating CP concentrations than in steers fed the same quantity of CP on a continuous basis. However, with steers fed low-quality roughage diets Simpson et al. (2001) and Ludden et al. (2003) noted no effect of oscillating CP on animal performance. This variability in results could be caused by several factors including timing of CP oscillations, CP concentrations in diets vs. animal requirements, degradability of CP, or diet composition/ferment ability. Cole (1999) hypothesized that oscillating dietary CP concentrations might increase N recycling between the rumen and large intestine of the gut. Nitrogen recycling is partially driven by carbohydrate fermentation in the rumen and large intestine (Egan et al., 1986), and ruminants fed high-concentrate diets would probably have greater ruminal and postruminal fermentation than those fed low-quality roughage diets (Owens et al., 1986). In addition,

Table 3. Performance of steers fed oscillating dietary crude protein concentrations or constant 12 or 14% CP diets in Trial 1 (four pens/treatment)

Item	12% CP	Oscillating	14% CP	SEM
Initial weight, kg	404	411	410	2.8
Average days on feed	115[a]	116[a]	105[b]	2.70
ADG, kg				
Day 28	2.73	2.70	2.81	0.06
Day 56	2.46	2.45	2.55	0.04
Final	1.64[c]	1.73[cd]	1.88[d]	0.04
DMI, kg/d				
Day 28	11.4	11.1	12.0	0.27
Day 56	11.9[c]	11.9[c]	12.9[d]	0.28
Final	11.5	11.6	12.5	0.29
Gain:feed ratio, g/kg				
Day 28	241	243	235	6.9
Day 56	208	205	199	3.4
Final	144[a]	150[ab]	152[b]	2.0

[a,b]Means in same row without a common superscript letter tend to differ ($P < 0.10$).
[c,d]Means in same row without a common superscript letter differ ($P < 0.05$).

oscillating CP did not seem to affect N retention when the supplemental CP was highly degradable (i.e., urea) but did when the supplemental CP contained appreciable amounts of ruminally undegradable CP (cottonseed meal: Cole, 1999) suggesting that some ruminally undegradable CP could potentially be fermented in the large intestine and the N recycled to the rumen. Collins and Pritchard (1992) also noted that supplemental protein degradability affected the animal response to oscillating dietary CP.

Carcass data of steers in Trial 1 are presented in Table 4. Steers fed the 14% CP diet tended ($P < 0.10$) to have lower dressing percent, smaller longissimus area, and higher quality grade than steers fed the oscillating CP regimen and tended ($P = 0.09$) to have higher quality grade than steers fed the 12% CP diet. Steers fed the oscillating CP regimen tended ($P = 0.08$) to have a lower percentage of carcasses that graded Low Choice or higher than the other treatments. The reason for

these differences in carcass characteristics is not apparent or expected because animals were fed to a constant end point. Steers fed the 12% CP diet tended ($P = 0.08$) to have a greater percentage of abscessed livers than steers fed the 14% or oscillating CP regimens. Again, the reason for this response is not clear.

Individually Fed Steer Study: Trial 2

The performance of steers in Trial 2 is presented in Table 5. Steers fed the 14% CP diet had greater ADG ($P = 0.08$) and gain:feed ($P = 0.04$) than steers fed the 12% CP diet, with steers fed the oscillating CP regimen being intermediate.

Nitrogen metabolism (Table 5) was affected by dietary regimen. As would be expected, steers fed the 14% CP diet had greater ($P = 0.04$) N intakes than steers fed the 12% or oscillating CP regimens. Steers fed the 14% CP diet also tended to have greater predicted

Table 4. Carcass data of steers fed oscillating dietary crude protein concentrations or constant 12 or 14% CP diets in Trial 1 (four pens/treatment)

Item	12% CP	Oscillating	14% CP	SEM
Live weight, kg	591	608	603	5.2
Hot carcass weight, kg	374	386	377	3.5
Dressing percent	63.4[b]	63.6[b]	62.5[c]	0.23
Fat thickness, mm	11.9	12.7	12.4	0.35
Longissimus area, cm^2	86.2[bc]	91.1[b]	83.6[c]	1.35
Marbling score[a]	4.48	4.49	4.70	0.08
Quality grade[a]	4.06[b]	4.03[b]	4.27[c]	0.09
Kidney, pelvic, heart fat, %	1.92	1.96	1.95	0.03
Yield grade	2.90	2.91	2.99	0.06
Quality grade distribution				
High Choice or greater, %	19.4	26.7	33.3	—
Low Choice or greater, %	83.9[b]	63.3[c]	86.7[b]	—
Liver abscesses, %	22.6[b]	6.7[c]	6.7[c]	—

[a]Marbling score: 3 = slight, 4 = small; 5 = modest (Herschler et al., 1995). Quality grade scores: 3 = Select, 4 = Low Choice, 5 = Medium Choice.
[b,c]Means in same row without a common superscript letter tend to differ ($P < 0.10$).

Cole et al.

Table 5. Performance and calculated nitrogen balance of steers individually fed oscillating dietary crude protein concentrations or constant 12 or 14% CP diets for 56 d in Trial 2 (least squares means, nine steers/treatment)

Item	12% CP	Oscillating	14% CP	SEM
Initial weight, kg	404	407	404	4.5
ADG, kg	1.64[a]	1.91[ab]	2.02[b]	0.07
DMI, kg	10.3	10.6	10.7	0.21
Gain:feed, g/kg	158[c]	179[cd]	189[d]	5.12
Predicted nitrogen metabolism				
N intake, g/d	197.7[c]	202.9[c]	239.8[d]	5.61
Empty body gain, kg/d[e]	1.21[a]	1.41[ab]	1.49[b]	0.05
Energy retained, mcal/d[f]	6.77[a]	8.11[ab]	8.54[b]	0.39
Protein retained, g/d[g]	139.5[c]	156.2[cd]	165.7[d]	4.23
N digested, % intake[h]	85.4	86.2	86.9	1.06
Fecal N, g/d[h]	28.6	28.0	31.4	2.24
Urine N, g/d[i]	146.8[c]	149.9[c]	181.8[d]	4.99
Urine N, % of excreted N	83.5	84.4	85.3	3.19
Retained N, % of N intake	11.3	12.3	11.1	1.42

[a,b]Means in same row without a common superscript letter tend to differ ($P < 0.10$).
[c,d]Means in same row without a common superscript letter differ ($P < 0.05$).
[e]Calculated as shrunk ADG × 0.956 as described by NRC (2000).
[f]Calculated as 0.635 × (empty $BW^{0.75}$) × (empty body $gain^{1.097}$) as described by NRC (2000).
[g]Calculate as shrunk body gain × [268 − (29.4 × retained energy/shrunk body gain)] as described by NRC (2000).
[h]Calculated using acid insoluble ash as an internal marker.
[i]Calculated as N intake − (fecal N + retained N).

empty-body gain ($P = 0.08$), energy retention ($P = 0.08$), and had greater predicted protein retention ($P = 0.03$) and urinary N excretion ($P = 0.04$) than steers fed the 12% CP diet. Steers fed the oscillating CP regimen had intermediate predicted empty-body gain and energy retention. However, steers fed the oscillating CP regimen tended ($P = 0.09$) to have greater predicted protein retention than steers fed the 12% CP diet. These results tend to agree with results of our earlier lamb N balance trial (Cole, 1999) and with the results of Collins and Pritchard (1992). However, they differ from the results of Ludden et al. (2002) and Simpson et al. (2001), who noted no effect of oscillating dietary CP on N retention of ruminants fed low-quality roughage diets. With a high-roughage diet, Ludden et al. (2002) noted lower apparent N digestibility in lambs fed oscillating CP than in lambs fed a constant dietary CP percentage. It is not known whether this was due to a lower true digestibility of the diet caused by decreased ruminal fermentation or if it is an indication of increased N recycling to the lower gut. In addition, Ludden et al. (2002) noted no significant effect of dietary CP concentration (13 vs. 15 vs. 17%) on N retention, suggesting the lower dietary CP concentration was adequate for the energy density of the diet, and that higher CP concentrations, or oscillating of dietary CP concentrations, would not be expected to increase N retention. Simpson et al. (2001) noted that lambs fed oscillating CP concentrations tended to have lower ruminal ammonia concentrations than lambs fed continuous CP concentrations; however, in all samples analyzed, the ruminal ammonia concentrations were well above that required for optimal ruminal microbial activity (Satter and Slyter, 1974). With steers fed a soybean meal supplement at

48-h intervals, Collins and Pritchard (1992) noted that ruminal ammonia concentrations peaked approximately 3 h after feeding and then declined steadily for the next 36 h. However, when steers were supplemented with corn gluten meal, a low degradable protein source, ruminal ammonia concentrations decreased from 3 to 12 h after feeding and then began to increase, suggesting N digested in the lower gut was being recycled to the rumen.

In agreement with previous studies (Cole, 1999; Simpson et al., 2001), calculated average urinary N excretion was not significantly affected by oscillating CP (compared to a constant 12% CP diet). With high-roughage diets, Collins and Pritchard (1992) noted that daily urinary N excretion changed within 24 h of a change in CP supplementation.

There was no day × treatment interaction ($P > 0.10$) for fecal pH, fecal DM, fecal N, fecal acid-insoluble ash, apparent DM digestibility, or apparent P digestibility; therefore, treatment main effects are presented in Table 6. Dietary treatment regimen did not significantly affect fecal pH. These results contrast with those of Haaland et al. (1982), who noted that fecal pH of mature Holstein cows fed 60% corn silage diets increased as dietary CP concentration increased (5.98, 6.20, and 6.36 for 11, 14, and 17% CP, respectively). Increasing dietary CP concentration from 14 to 17% also increased the buffering capacity of ruminal fluid when the pH was between 6.0 and 4.5 (Haaland et al., 1982).

Fecal DM concentration was greater ($P < 0.05$) in steers fed the 14% and oscillating CP dietary regimens than in steers fed the 12% CP regimen. The reason for this difference is not apparent. Dietary treatment regimen did not significantly affect fecal N concentra-

Table 6. Feces composition of steers individually fed oscillating dietary crude protein concentrations or constant 12 or 14% CP diets in Trial 2
(least squares means, nine steers/treatment)

Item	12% CP	Oscillating	14% CP	SEM
pH	6.70	6.58	6.60	0.042
Dry matter, %	22.52[b]	24.40[c]	24.56[c]	0.368
N, % DM	3.06	3.10	3.17	0.036
P, % DM[a]	0.53	0.55	0.54	0.021
Day 14	0.48[bc]	0.38[c]	0.53[b]	0.034
Day 15	0.52[de]	0.43[e]	0.56[d]	0.038
Day 16	0.50[d]	0.60[e]	0.51[d]	0.037
Day 17	0.62[bc]	0.74[c]	0.55[b]	0.053
N:P ratio mean[a]	6.69	6.41	6.38	0.234
Day 14	7.48[de]	7.94[e]	6.59[d]	0.446
Day 15	7.16[de]	7.48[e]	6.14[d]	0.467
Day 16	6.61	5.99	7.01	0.425
Day 17	5.51[bc]	4.25[c]	5.77[b]	0.436
Acid-insoluble ash, %	0.98	1.02	0.88	0.060
Dry matter digestibility, %	90.2	90.5	89.8	0.514
P digestion,%	79.4	81.0	82.2	0.912

[a]Day × treatment interaction ($P < 0.05$). Within the oscillating CP regimen, mean values for d 14 and 15 differ from d 16 and 17 ($P < 0.05$).

[b,c]Means in same row without a common superscript letter differ ($P < 0.05$).

[d,e]Means in same row without a common superscript letter tend to differ ($P < 0.10$).

tion, fecal acid-insoluble ash concentration, apparent DM digestibility, or apparent P digestibility. These results agree with studies in lambs fed high concentrate diets (Cole, 1999).

The sample day × treatment interaction was significant ($P = 0.03$) for fecal P concentration and fecal N:P ratio. Fecal P concentration of steers fed the 12% and 14% CP diets was relatively consistent across days, whereas fecal P concentrations varied ($P = 0.04$) from 0.38 to 0.74% (DM basis) in steers fed the oscillating CP regimen. The change in fecal N:P ratio was the result of the changes in the fecal P concentration of steers on the oscillating CP regimen. The reason for the change in fecal P concentration of steers on the oscillating CP regimen is not clear because the 10 and 14% CP diets had similar P concentrations. Like N, P can be recycled between segments of the ruminant gut. The change in fecal P concentration could be the result of changes in movement of P into and out of the lower gut, differences in urinary P excretion, or the result of differences in other forms of metabolic fecal P. Cole (1999) noted variable effects of oscillating dietary CP on P retention of lambs. These variable effects may be related to differences in CP source. Scott et al. (1971) reported that 16 to 25% of the acid excreted in the urine of calves fed a high-concentrate diet is in the form of phosphate ions and that excretion of urinary buffers was affected by both dietary roughage concentration and CP source. In steers and sheep fed a high-concentrate diet, urinary phosphate acid excretion increased from 75 mmol/d in animals fed soybean meal to 165 mmol/d in animals fed fish meal (Scott, 1972). However, it is not clear whether this was due to such factors as ruminal protein degradability or dietary P concentrations.

Plasma metabolite concentrations are presented in Table 7. The sample day × treatment interaction was significant for plasma urea-N but not for plasma glucose, lactate, ammonia, or chloride during sample d 14 through 17 and 42 through 45. The day × treatment interaction for plasma urea-N appeared to be the result of differences in the magnitude of differences, rather than direction of differences because day did not affect the plasma urea-N concentrations of steers fed the 12 and 14% CP diets but did affect plasma urea-N concentrations of steers fed the oscillating CP regimen. On all sampling days, steers fed the 12% and oscillating CP regimens had lower ($P = 0.009$) plasma urea-N concentrations that steers fed the 14% CP diet. Averaged across the four sample days, dietary regimen did not significantly affect plasma glucose, lactate, or chloride. Plasma ammonia concentrations of steers fed the 14% CP diet tended to be greater ($P = 0.055$) than the remaining treatments.

Mean plasma urea-N, ammonia, and chloride concentrations were greater ($P = 0.02$) in samples collected on d 42 through 45 than in samples collected on d 14 through 17. Plasma urea-N concentrations are an indicator of N status in ruminants (Preston et al., 1965; Pfander et al., 1975). Johnson and Preston (1995) suggested that plasma urea N values greater than 5 to 8 mg/100 mL were indicative of excessive N intake and N wastage. However, results of the present study suggest the plasma urea-N concentration at which excessive N intake is indicated may be slightly greater than 8 mg/100 mL. Steers fed the 12% CP diet had plasma urea-N concentrations greater than 9 mg/100 mL; however, performance was greater ($P = 0.04$) in steers fed the 14% CP diet. These differences in the apparent plasma urea-N concentration that indicate dietary N

Table 7. Plasma metabolite concentrations of steers fed oscillating dietary crude
protein concentrations or constant 12 or 14% CP diets in Trial 2
(least square means, nine steers/treatment)

Metabolite and day[a]	12% CP	Oscillating	14% CP	SEM
Glucose, mg/100 mL				
Days 14 to 17	101.9	94.8	104.5	1.47
Days 42 to 45	100.0	93.4	96.6	1.28
Urea N, mg/100 mL[b]				
Days 14 to 17 mean	9.28	7.94	11.48	0.232
Day 14	9.73[c]	8.66[c]	11.86[d]	0.434
Day 15	9.25[d]	6.74[c]	11.78[d]	0.512
Day 16	8.44[c]	7.82[c]	11.70[d]	0.509
Day 17	9.68[c]	8.54[c]	10.36[d]	0.368
Days 42 to 45 mean	10.48	10.25	13.28	0.364
Day 42	10.36[c]	10.46[c]	13.16[d]	0.458
Day 43	10.64[c]	9.10[c]	14.30[d]	0.735
Day 44	10.76[c]	10.26[c]	13.06[d]	0.472
Day 45	10.16[c]	11.16[c]	12.56[d]	0.552
Lactate, mg/100 mL				
Days 14 to 17	25.0	20.7	28.5	1.14
Ammonia, μg/mL				
Days 14 to 17	5.40	5.43	6.59	0.39
Days 42 to 45	6.32	6.95	8.34	0.43
Chloride, mEq/L				
Days 14 to 17	84.9	84.9	84.4	1.00
Days 42 to 45	91.0	91.8	89.1	0.98

[a]Day 14 = first day calves on oscillating CP regimen were fed 10% CP diet, Day 15 = second consecutive
day fed 10% CP; Day 16 = first day fed 14% CP diet and Day 17 = second consecutive day calves were fed
14% CP diet.

[b]Day × treatment interaction ($P < 0.05$).

[c,d]Means in same row without a common superscript letter differ ($P < 0.05$).

excess could be affected by other factors, such as the degradability of dietary CP or fermentation rate of dietary carbohydrate.

Based on previous results (Preston et al., 1965; Pfander et al., 1975; Collins and Pritchard, 1992), we suspected that the plasma urea-N concentrations of steers on the oscillating CP regimen would fluctuate with changes in dietary CP concentration. This anticipated fluctuation did occur. Plasma urea-N concentrations of steers fed the oscillating CP regimen were lowest on d 14 and 43, after they had been fed the 10% CP diet for 2 consecutive days. Highest values occurred after being fed the 14% CP diets for 1 or 2 d. However, even after 2 d of being fed the 14% CP diet, plasma urea-N concentrations were lower ($P < 0.05$) than values for steers on the 14% CP diet and not different from steers fed the 12% CP diet. The results from d 14 through 17 agree with Ludden et al. (2003), who also noted that mean plasma urea-N concentrations were greater in steers fed a continuous amount of CP than in steers fed a similar quantity of CP on an oscillating basis. They also agree with Simpson et al. (2001), who noted that on days when the higher CP diet was fed to lambs on an oscillating CP regimen, their plasma urea-N concentrations were lower than lambs continuously fed the higher CP diet.

Arterial blood variables and apparent acid-base balance are presented in Table 8. The day of sampling did not significantly affect arterial blood values; therefore, overall means are presented. Steers fed the 12% CP diet tended to have greater ($P = 0.08$) hematocrit than steers fed the 14% or oscillating CP regimens. Steers fed the oscillating CP regimen tended to have greater ($P = 0.08$) arterial bicarbonate, total carbon dioxide, blood base excess, and extracellular fluid base excess than steers fed the 14% CP diet, with steers fed the 12% CP diet being intermediate. The reasons for these differences are not apparent.

Heitman and Bergman (1978) noted that induced metabolic acidosis in sheep led to increased renal production of ammonia, apparently to facilitate urinary elimination of excess hydrogen ions, and that hepatic and renal glutamine metabolism as well as blood pH and base excess were affected by acidosis. Similarly, Trenkle (1979) noted that feeding high-concentrate diets increased the quantity of acids absorbed from the rumen and simultaneously increased renal ammoniagenesis to apparently neutralize the excess acids. Scott et al. (1971) reported that 75 to 84% of the acid excreted in urine of calves fed a high-concentrate diet is in the form of ammonium ions; the remainder is in the form of acid phosphate. In a later study, Scott (1972) noted that excretion of urinary buffers can be affected by both dietary roughage concentration and CP source. Sheep and calves fed high-concentrate diets supplemented with fish meal had lower blood base excess and

Table 8. Arterial blood acid-base metabolites of steers individually fed oscillating dietary crude protein concentrations or constant 12 or 14% CP diets in Trial 2 (least square means, nine steers/treatment)

Item	12% CP	Oscillating	14% CP	SEM
Hematocrit, %	41.5[a]	39.0[b]	39.9[b]	0.36
pH	7.39	7.40	7.39	0.005
pCO_2, mm Hg	41.8	41.6	40.0	0.42
pO_2, mm Hg	88.2	86.6	82.2	2.68
Bicarbonate, mM/L	24.2[ab]	25.2[a]	23.4[b]	0.29
Total CO_2, mM/L	25.3[ab]	26.4[a]	24.5[b]	0.30
Base excess of blood, mM/L	0.68[ab]	1.89[a]	0.13[b]	0.30
Base excess of extracellular fluid, mM/L	−0.40[ab]	0.89[a]	−1.14[b]	0.34
O_2 saturation, %	94.2	93.5	93.3	0.36

[a,b]Means in same row without a common superscript letter tend to differ ($P < 0.10$).

blood bicarbonate concentrations than animals fed either a high-roughage diet or a high-concentrate diet supplemented with soybean meal. Urine pH was alkaline in animals fed a high-roughage diet, neutral when fed a high-concentrate diet containing soybean meal, and acidic when fed a high-concentrate diet supplemented with fish meal. Urinary acid excretion (ammonium + phosphate) increased from 36 mmol/d (roughage) to 105 mmol/d (soybean meal: 28% as acid phosphate) to 331 mmol/d (fish meal: 50% as acid phosphate). Based on these results, it seems that ammonia absorbed from the rumen may indeed be important as a systemic buffer in finishing cattle.

Feeding diets high in CP and/or urea is a common practice in commercial beef cattle feed yards feeding high-concentrate diets (Galyean, 1996). Many consultants think that the additional systemic ammonia provided by these diets may serve to buffer the high-acid loads that occur. Based on this premise, feeding lower CP (or DIP) diets or oscillating between a relatively high and low CP (or DIP) diet could potentially cause additional problems with acidosis. In Trial 1, steers fed the 12% CP diet tended ($P = 0.08$) to have a greater percentage of liver abscesses than steers fed the 14% CP diet, suggesting that the higher CP diet may have had beneficial effects on ruminal or systemic buffering capacity. However, in Trial 2, the concentrations of all acid-base constituents measured were well within normal ranges for cattle (Houpt, 1982), thus suggesting that systemic buffering capacity was not altered by dietary regimen under the conditions of this study.

Implications

The effects of confined animal feeding operations on the environment are of growing concern in many parts of the world. Among those concerns are the loss of nitrates to ground or surface waters and emissions of ammonia to the atmosphere. It may be possible to use dietary means to "indirectly" decrease these nitrogen losses via decreasing nitrogen inputs and subsequent nitrogen excretion. However, if animal performance is adversely affected, total nitrogen loses could actually

be increased due to increased days on feed. Additional research is needed to determine whether oscillating dietary crude protein concentrations can decrease nitrogen excretion without adversely affecting animal performance.

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